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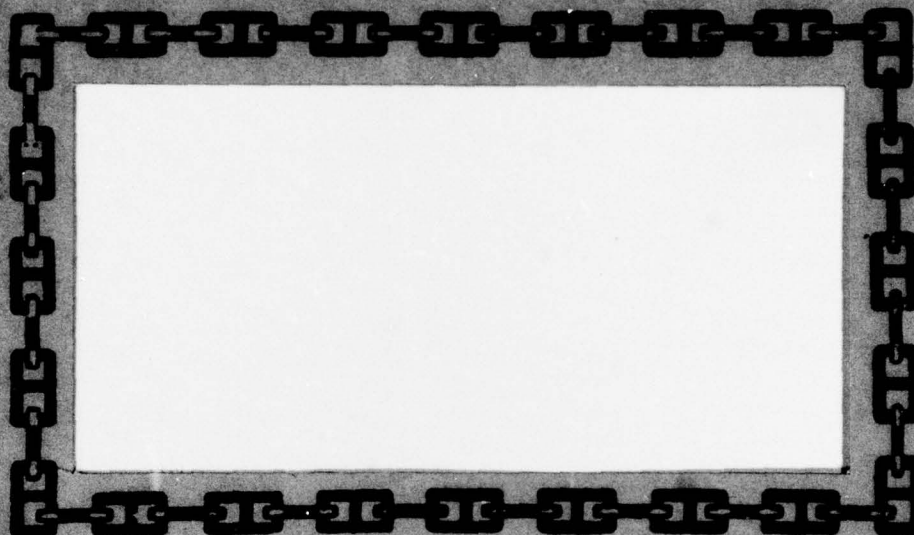
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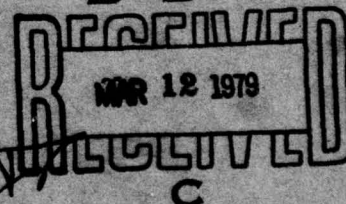
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⑥ CARBON DIOXIDE ABSORBENT CANISTER
STUDIES OF THE HOT WATER HEATED,
HELIUM-OXYGEN MODE, MK 12 SURFACE
SUPPLIED DIVING SYSTEM.

By:

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⑪ 1 December 1978

⑨ Final Rept.



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Within the body of the canister and hot water heating of the canister. Three canister studies were performed in 40°F water at 390 feet of seawater. The divers performed 6-minute work periods, separated by 4 minutes of rest, at a work rate of 50 watts on a pedal ergometer. The work-rest sequence was selected to approximate an average metabolic production of 1.5 liters of CO₂ per minute and simulate a hard working dive. The work-rest sequence proceeded until canister breakthrough, defined as the point at which canister effluent reached 0.5% Surface Equivalent Value (SEV) (3.8 mmHg). The mean CO₂ value of the three canisters at 9 hours was 0.2% SEV. One study was continued until breakthrough, 0.5% SEV, which occurred at 10 hours. It is unlikely that any operational dive would involve continuous, moderate work for 9 hours. Therefore, the results clearly demonstrate that the MK 12 SSDS helium-oxygen mode would support a diver for the design goal of 9 hours.

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ABSTRACT

Testing of previous prototype MK 12 SSDS carbon dioxide absorbent canisters indicated that initial cooling of exhaled gas with subsequent gas rewarming within the CO₂ absorbent bed led to drying of the absorbent material and deterioration in performance. The first two prototypes tested in manned dives had shorter CO₂ scrubbing durations than desired. The recirculator assembly was modified by incorporation of two moisture retaining condensers within the body of the canister and hot water heating of the canister. Three canister studies were performed in 40°F water at 390 feet of seawater. The divers performed 6-minute work periods, separated by 4 minutes of rest, at a work rate of 50 watts on a pedal ergometer. The work-rest sequence was selected to approximate an average metabolic production of 1.5 liters of CO₂ per minute and simulate a hard working dive. The work-rest sequence proceeded until canister breakthrough, defined as the point at which canister effluent reached 0.5% Surface Equivalent Value (SEV) (3.8 mmHg). The mean CO₂ value of the three canisters at 9 hours was 0.2% SEV. One study was continued until breakthrough, 0.5% SEV, which occurred at 10 hours. It is unlikely that any operational dive would involve continuous, moderate work for 9 hours. Therefore, the results clearly demonstrate that the MK 12 SSDS helium-oxygen mode would support a diver for the design goal of 9 hours.

CARBON DIOXIDE ABSORBENT CANISTER STUDIES
OF THE HOT WATER HEATED, HELIUM-OXYGEN
MODE, MK 12 SURFACE SUPPLIED DIVING SYSTEM

The first two prototype helium-oxygen mode MK 12 SSDS carbon dioxide absorbent canisters tested in manned dives at the Navy Experimental Diving Unit had shorter carbon dioxide scrubbing durations than planned (O'Bryan, 1977, 1978). The carbon dioxide absorbent canister design goal was a canister with sufficient carbon dioxide absorbing capacity to support a diver doing moderate work, equivalent to a carbon dioxide production of 1.5 liters per minute (lpm), for a period of 9 hours. This duration would exceed all operational requirements.

In graded exercise studies performed during the same two dives, the helmet ventilation was shown to meet specific physiological standards and was able to support divers performing severe work equivalent to 3 liters per minute (lpm) of CO_2 production. The standards for helmet ventilation and the characteristics of the MK 12 helmet have been reviewed by O'Bryan (1977, 1978); and Thalmann, Crothers and Knott (1974).

The MK 12 SSDS recirculator assembly consists of a manifold, an ejector, an emergency gas bottle, associated valves and hoses, and a CO_2 absorbent bed contained in a 5.7 liter canister (Figures 1 and 2). During normal

operations, surface-supplied gas is delivered to the manifold of the MK 12 SSDS recirculator assembly. Here the gas is directed to the ejector, which is positioned in such a way that a venturi action secondary to gas flow through a .028 inch diameter orifice entrains gas from the CO₂ absorbent bed, drawing additional helmet gas into the canister, and sending scrubbed and supply gas back into the helmet. Thus, a small ejector flow creates a system flow sufficient for adequate helmet ventilation and carbon dioxide absorption.

Mixed gas flowing into the helmet through the inlet hose from the recirculator, passes through a one-way valve into ducting that directs the flow as close as possible to the diver's breath intake. Returning gas is removed from the helmet through ducting on each side of the diver's face and then back to the recirculator through one-way valve and outlet hose. Ducting arrangement and helmet flow rate reduce CO₂ buildup in the helmet.

Evaluation of the MK 12 SSDS indicated that initial cooling of exhaled gas with subsequent gas rewarming within the carbon dioxide absorbent bed led to significant drying of CO₂ absorbent material and deterioration in performance. The MK 12 SSDS recirculator assembly was modified by the incorporation of two moisture retaining condensers

within the body of the canister and hot water heating of the canister for use in water of 50°F and below.

Surface supplied 110°F water at the diver at a rate of 0.75 to 1.0 gallons per minute is forced through orifices directly onto the inlet and outlet adapters and the canister cap. Hot water from the orifices then flows into the backpack. Heating with hot water in conjunction with use of the 12-pound canister and insulated shrouds on the inlet and outlet hoses was expected to provide a 9.0-hour dive duration at 29°F. The attendant heating of the breathing gas might also improve the comfort of the diver and thus increase the dive duration.

Unmanned studies have indicated that the life expectancy of this canister, utilizing High Performance Sodasorb (W. R. Grace Chemical Corporation), was in excess of 11 hours when subjected to an average load of 1.5 lpm of CO₂ when the helmet ventilation rate was 170 lpm, measured at the dive depth, (6 actual cubic feet per minute, ACFM). To confirm the capability of the prototype MK 12 SSDS to support a working diver, the system was evaluated at its operational depth.

METHODS

Six experienced U.S. Navy male divers served as subjects. All subjects performed extensive calisthenics and distance runs up to 7 km, five days per week for nine weeks prior to the study. In addition, each man performed in excess of twenty underwater work cycles, similar to the experimental protocol, during this work-up period.

All studies were performed in 40°F (4.5°C) water at 390 FSW in a wet chamber of the Navy Experimental Diving Unit. Each diver wore a prototype MK 12 SSDS and was thermally protected by a MK 12 hot water outergarment. The carbon dioxide absorbent was High Performance Sodasorb. The supply gas was 94% Helium-6% Oxygen (Oxygen Partial Pressure, P_{O_2} , 584 mmHg at 390 FSW). The gas mixture was delivered to the ejector manifold via 600 feet of MK 12 umbilical hose at an overbottom pressure of 50 psi which produced a helmet ventilation of 170 lpm (6 ACFM). This ventilation was reported by Thalmann et al. (1974) to prevent helmet P_{CO_2} from exceeding the Navy limit of 15.2 mmHg or 2% Surface Equivalent Value (SEV) with a diver performing work equivalent to an oxygen consumption (\dot{V}_{O_2}) of 3 liters per minute.

The protocol consisted of six-minute work periods, separated by four minutes of rest, at a work rate of 50 watts on a modified pedal ergometer (James, 1976) mounted

vertically on a frame. The work-rest sequence was selected to approximate an average metabolic production of 1.5 liters of CO_2 per minute.

A continuous analysis of helmet, canister inlet, and canister outlet CO_2 was recorded. Helmet oxygen was also measured. This was accomplished by venting gas samples via an 1/8" O.D. tube at an appropriate flow rate to a mass spectrometer located outside the chamber. Heart rate was measured by chest electrocardiographic leads.

The work-rest sequence proceeded until canister breakthrough, defined as the point at which canister effluent P_{CO_2} attained a value of 0.5% SEV (3.8 mmHg), and then continued until the canister effluent reached 1.0% SEV (7.6 mmHg). The first study was to determine the time in hours until breakthrough. The second and third studies were planned not to exceed 9 hours. As divers became fatigued prior to canister breakthrough, another diver was substituted, and the experiment continued. During the diver changeout the recirculator was left operating to maintain absorbent activity.

RESULTS

Figure 3 portrays canister effluent P_{CO_2} versus time. The first canister maintained the outlet below

0.5% SEV (3.8 mmHg) for 10 hours. The other two canister experiments did not reach breakthrough and were stopped as planned at 9 hours. The mean P_{CO_2} of the three canisters at 9 hours was 0.2% SEV.

The 84% helium - 6% oxygen supplied via the umbilical was equal to 584 mmHg or 0.77 ATA oxygen partial pressure. Measurement of the mean inspired helmet oxygen partial pressure was 516 mmHg or 0.64 ATA at rest and 432 mmHg or 0.57 ATA during work. Heart rates were 80 ± 15 (mean \pm SD) at rest and 120 ± 12 during exercise.

DISCUSSION

The physiological rationale for maintaining limits on CO_2 inhaled from the helmet have been reported in previous MK 12 studies (Thalmann, Crothers and Knott, 1974; O'Bryan, 1977, 1978).

The purpose of this study was to establish the life expectancy of the CO_2 absorbent bed when simulating a hard working dive. The moderate work rate CO_2 production of 1.5 lpm was maintained by a work-rest sequence for the total test period. This testing method is applied uniformly to all canister testing so that diverse underwater breathing apparatus characteristics can be compared.

The rationale for defining canister breakthrough as 0.5% SEV is to prevent inspired CO_2 from ever reaching levels which would adversely effect the diver. As evidenced from Fig. 3, once the canister effluent CO_2 reaches 0.5% SEV, it rises rapidly thereafter. Thus, to prevent the canister from being used on this steep, rising portion of the curve, the canister is considered spent when an effluent CO_2 level of 0.5% SEV is reached.

It is unlikely that any operational dive would involve continuous moderate work for 9 hours. Therefore, the results clearly demonstrate that the MK 12 SSDS helium-oxygen mode would support a diver for the design goal for 9 hours.

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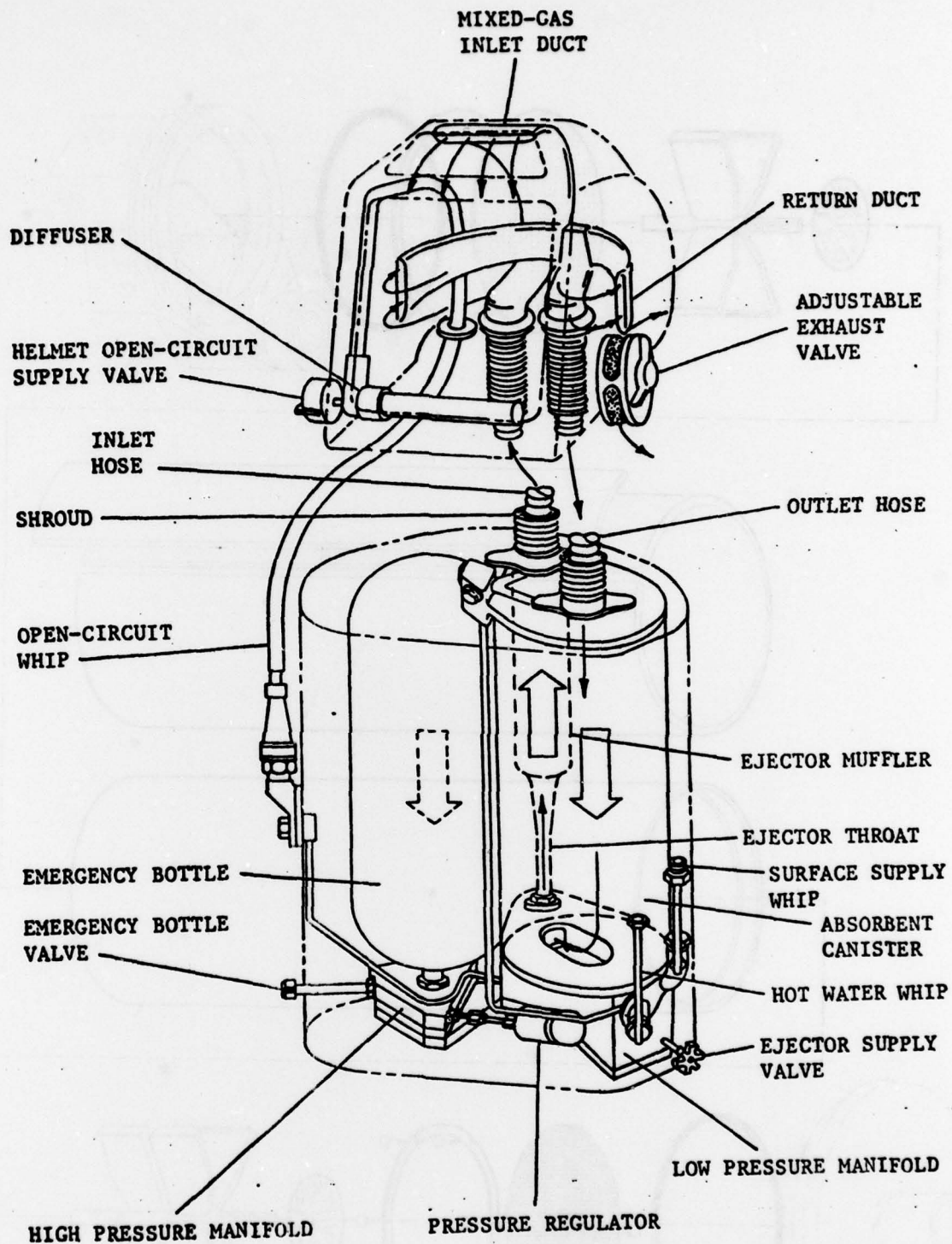


Figure 1 Mixed Gas System Flow, Semi-closed

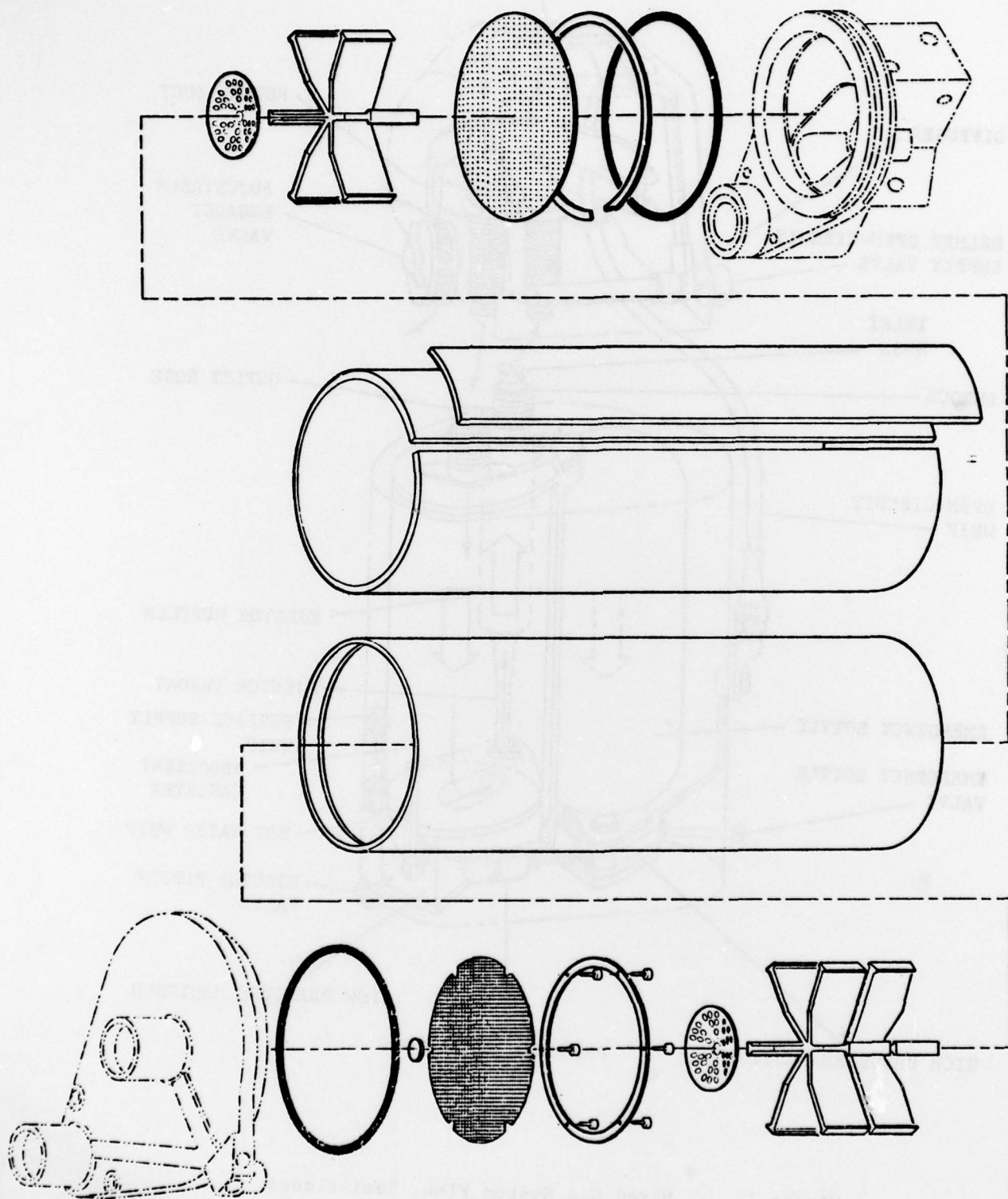


Figure 2. Carbon Dioxide Absorbent Canister

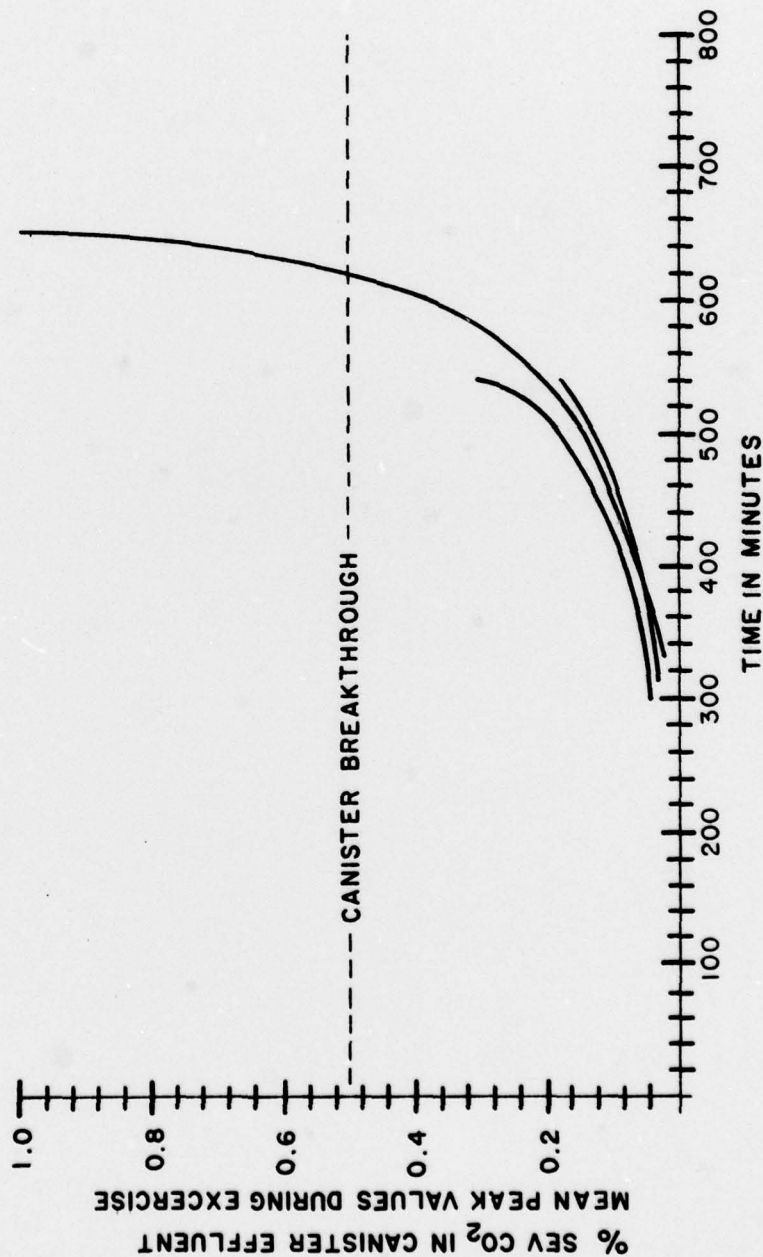


Figure 3 MK 12 Canister Breakthrough, 390 FSW